NMSSM Higgs Physics

ZHEN LIU

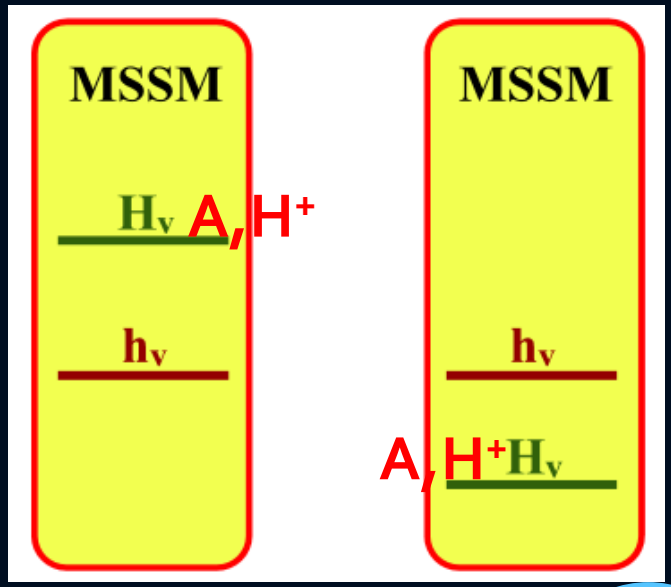
University of Pittsburgh

Base upon work with **N. Christensen, T. Han and S. Su**

Arxiv:**1303.2113**

SNOWMASS EF @ BNL

Overview: MSSM



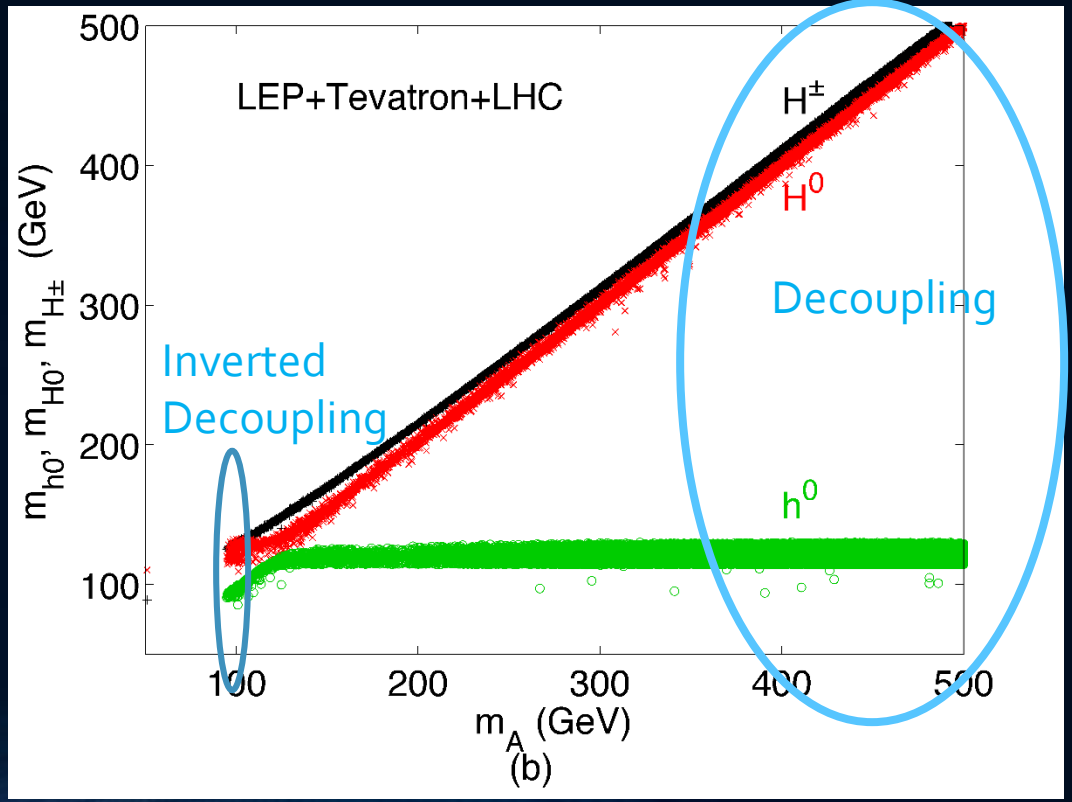


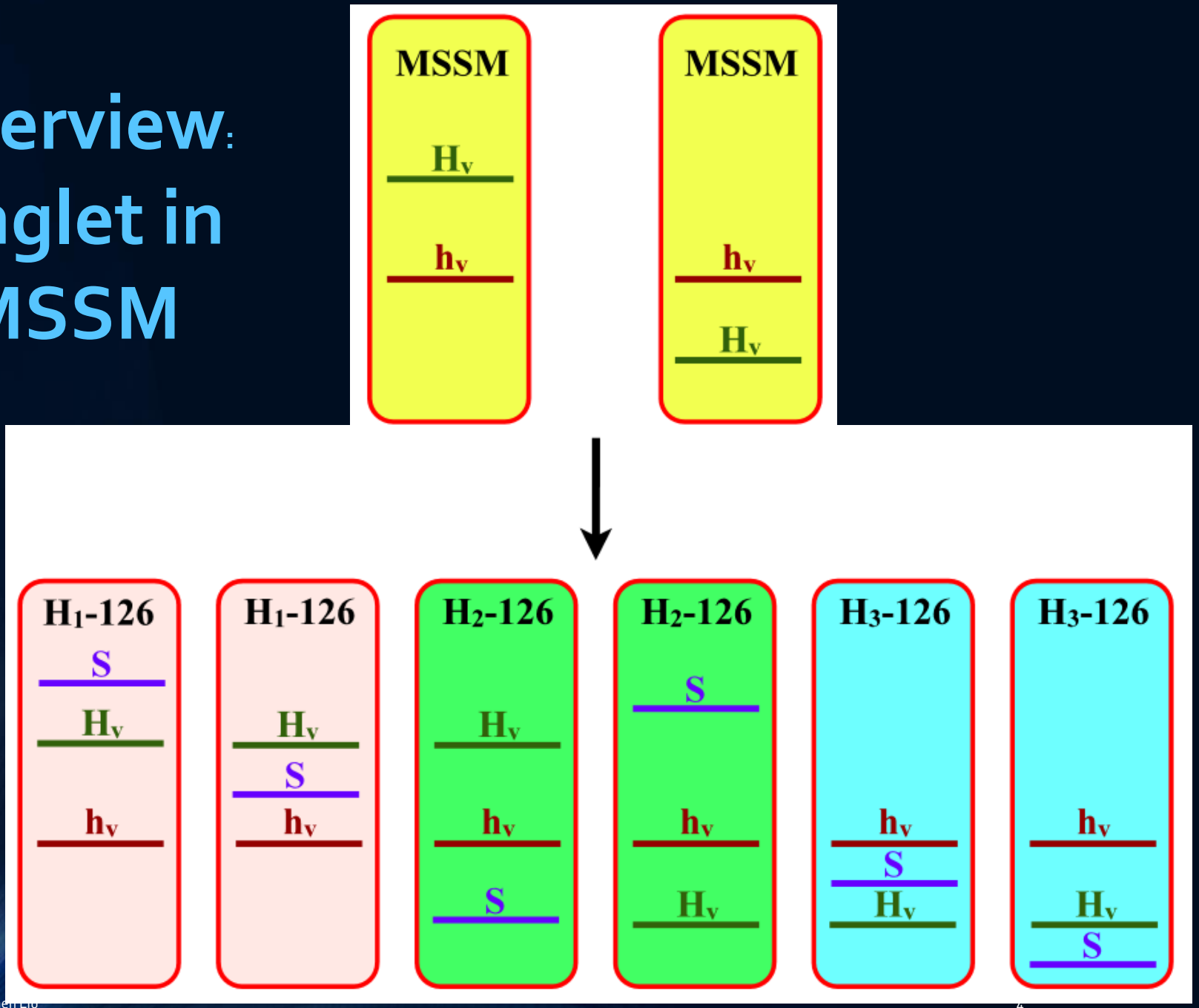
Fig. from Christensen, Han and Su, arxiv: 1203.3207

Overview: Singlet in NMSSM

- New matter content comparing to MSSM:
  - one more CP even Higgs (3 in total);
  - one more CP odd Higgs (2 in total);
  - one more neutralino (5 in total).
- The singlet field is not charged under gauge symmetry groups$\rightarrow$:
  - Only couple to Higgs(Higgsino) at tree level.
  - Couple to others in MSSM at least one-loop order.
  - Corrections to MSSM Higgs couplings to others in MSSM at least two-loop order.
  - Mix
  - Dilute
  - Push-up/Pull-down

$$(m^2_{h_v})_{\text{tree}} = m_Z^2 \cos^2 2\beta + \frac{1}{2}(\lambda v)^2 \sin^2 2\beta$$

Overview: Singlet in NMSSM



Overview

- **Lots of work on (125 GeV) Higgs in NMSSM framework ...**

Gunion et. al, 1201.0982
Ellwanger 1112.3548
King et. al., 1201.2671
Cao et. al., 1202.5821
EllWanger et. al., 1203.5048
Benbrik et. al., 1207.1096
Gunion et. al., 1207.1545
Gunion et. al., 1208.1817
Cheng et. al., 1207.6392
Belanger et. al., 1208.4952
Agashe et. al., 1209.2115
Belanger et. al., 1210.1976

Heng, 1210.3751
Choi et. al., 1211.0875
King et. al., 1211.5074
Dreiner et. al., 1211.6987
... many other Jack's paper ...
(incomplete list)

- **H3 heavy, m_A large**
- **H1 126 or H2 126**
- **h_V/S mixing**

Parameters

- **MSSM**

  m_A, tan β, μ, (v)

  M3SQ, M3SU, A_t

- **NMSSM**

  λ, κ, A_λ, A_κ, tan β, v_s, (v)

  M3SQ, M3SU, At

- **NMSSM**

  λ, κ, m_A, A_κ, tan β, μ, (v)

  M3SQ, M3SU, A_t

Scanning Strategy

Study the consequence of

(I) current Higgs search limit of 95% CL limit on σXBr

(II) H_i in the mass range of 124 - 128 GeV

(III) $\sigma XBr(gg \rightarrow H_i \rightarrow \gamma\gamma)_{NMSSM} > 80\% (\sigma XBr)_{SM}$

$\sigma XBr(gg \rightarrow H_i \rightarrow WW/ZZ)_{NMSSM} > 40\% (\sigma XBr)_{SM}$

Chargino mass, Stop mass, Sbottom mass > 100 GeV

$1 < \tan\beta < 10$

$0 \text{ GeV} < m_A < 200 \text{ GeV}$

$100 \text{ GeV} < \mu < 1000 \text{ GeV}$

$0.01 < \lambda < 1$

$0.01 < \kappa < 1$

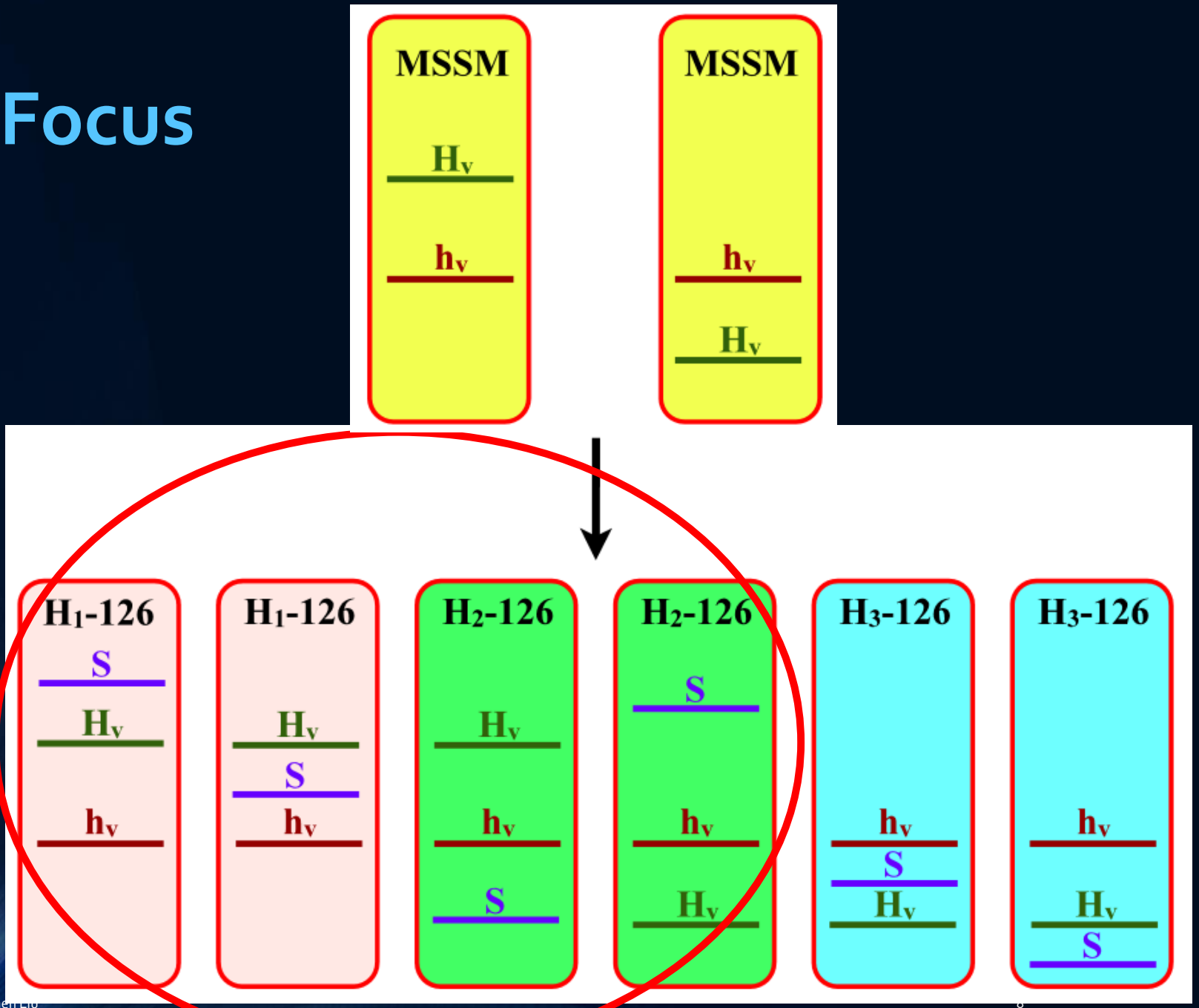
$-1200 \text{ GeV} < A_\kappa < 200 \text{ GeV}$

$100 \text{ GeV} < M_{3SU}, M_{3SQ} < 3000 \text{ GeV}$

$-4000 \text{ GeV} < A_t < 4000 \text{ GeV}$

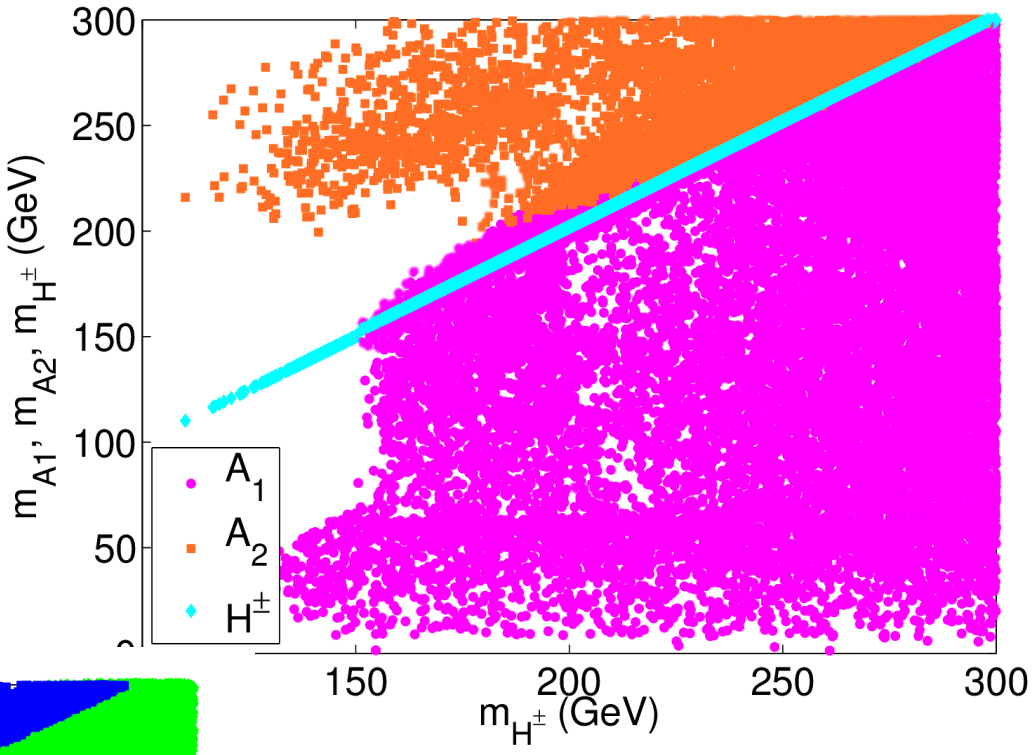
decoupling other parameters (3 TeV)

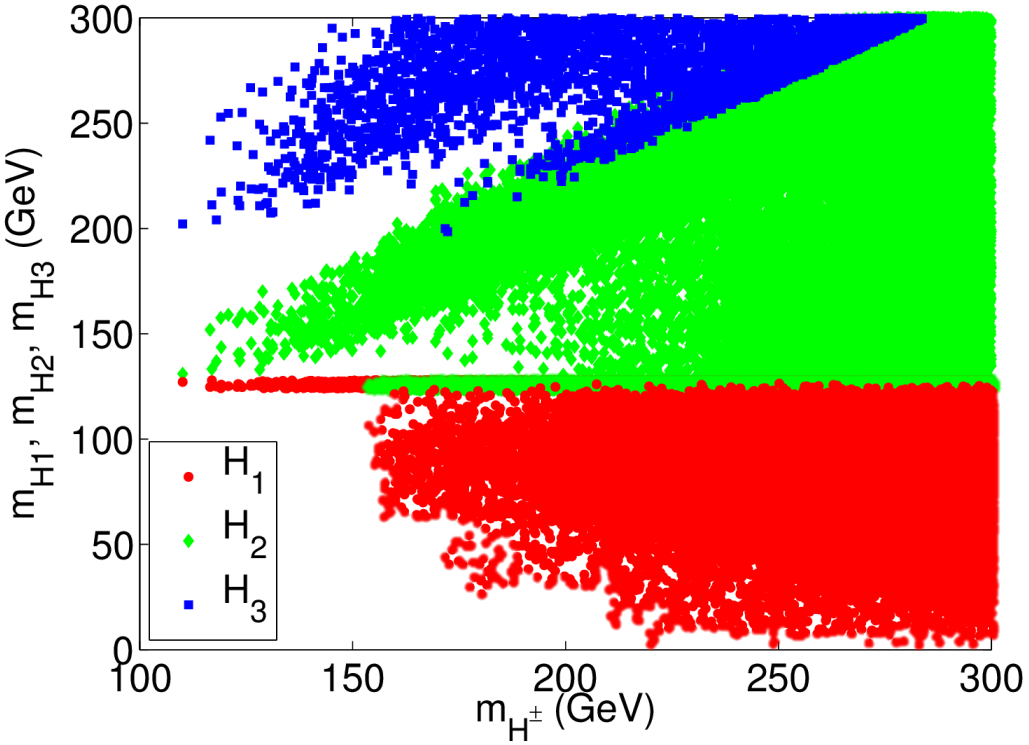
Our Focus


MSSM
H_V
h_V
MSSM
h_V
H_V
H_1-126
S
H_V
h_V
H_1-126
H_V
S
h_V
H_2-126
H_V
h_V
S
H_2-126
S
h_V
H_V
H_3-126
h_V
S
H_V
H_3-126
h_V
H_V
S

$$m_{H^\pm}^2 = m_A^2 + m_W^2 - \tfrac{1}{2}(\lambda v)^2$$

- Higgs masses receive large radiative corrections from stop loops
- $m_{Hpm} \sim m_{Aloop}$ (so-called m_A in MSSM)
- in NMSSM, m_{Aloop} is
- not physical Higgs mass;
- m_{A1}, m_{A2} after diagonalization



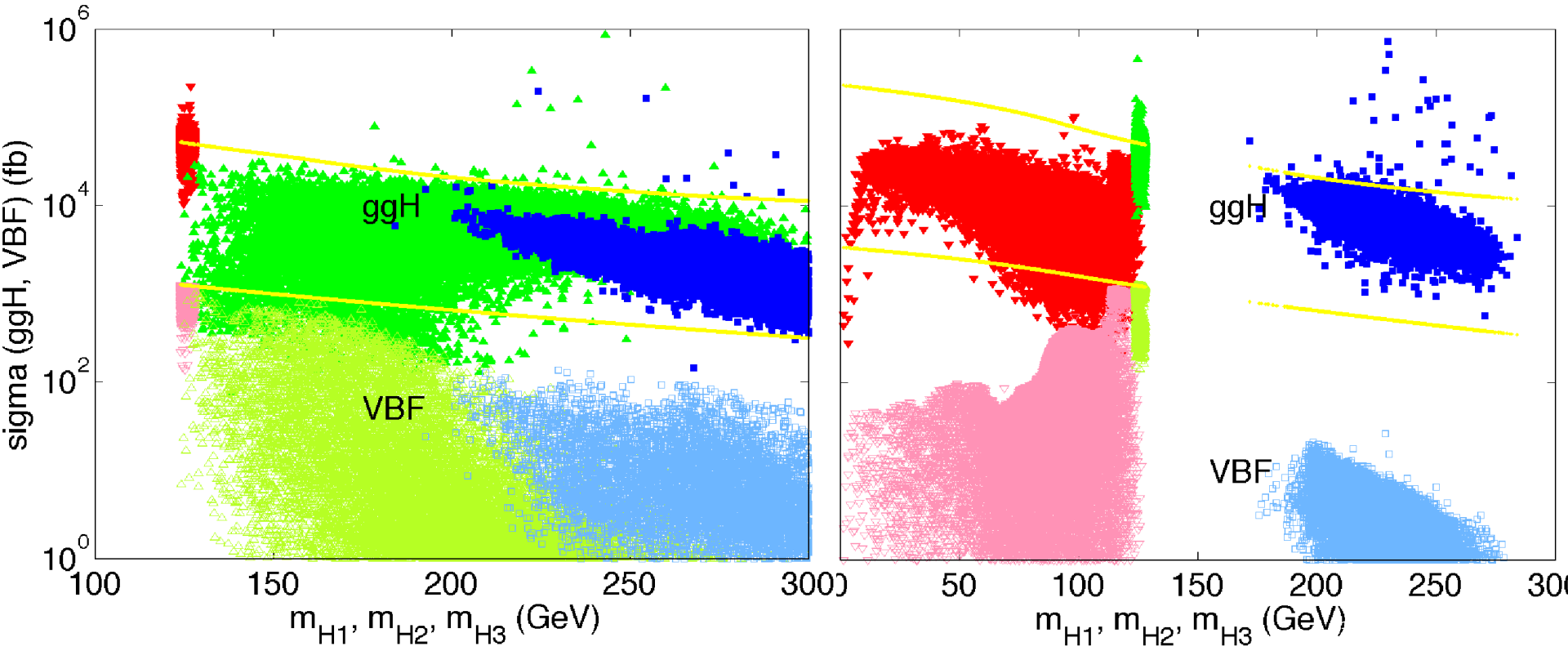


Mass Spectrum

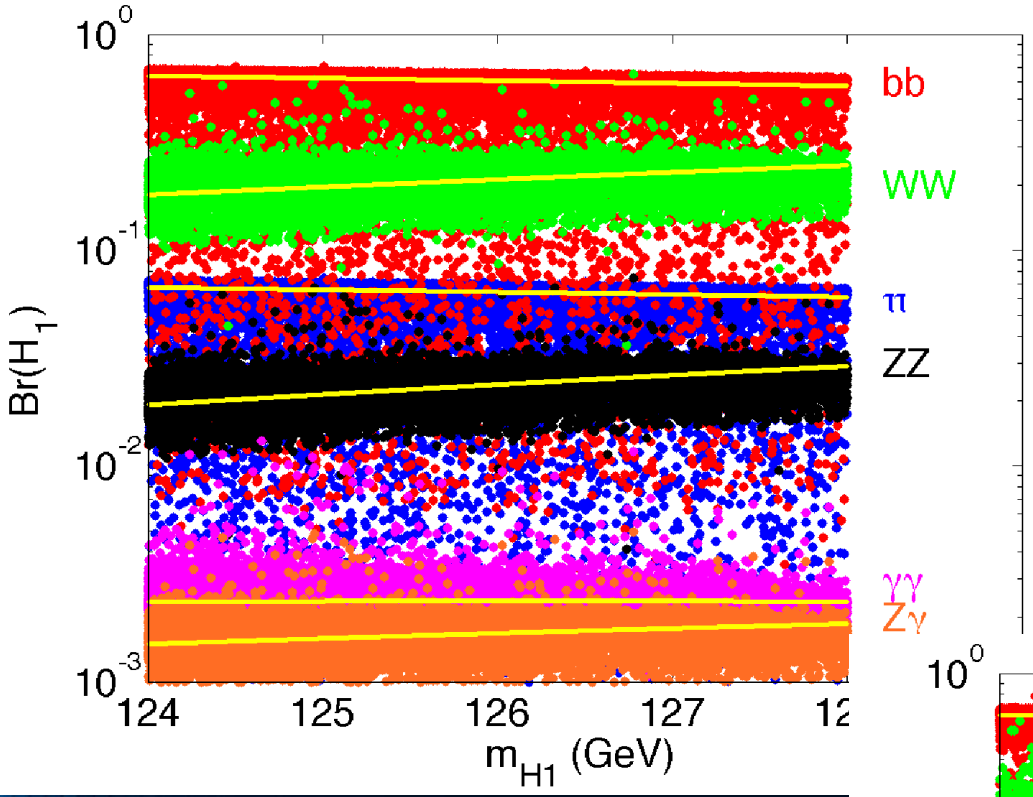
Higgs Productions: CP-Even Sector

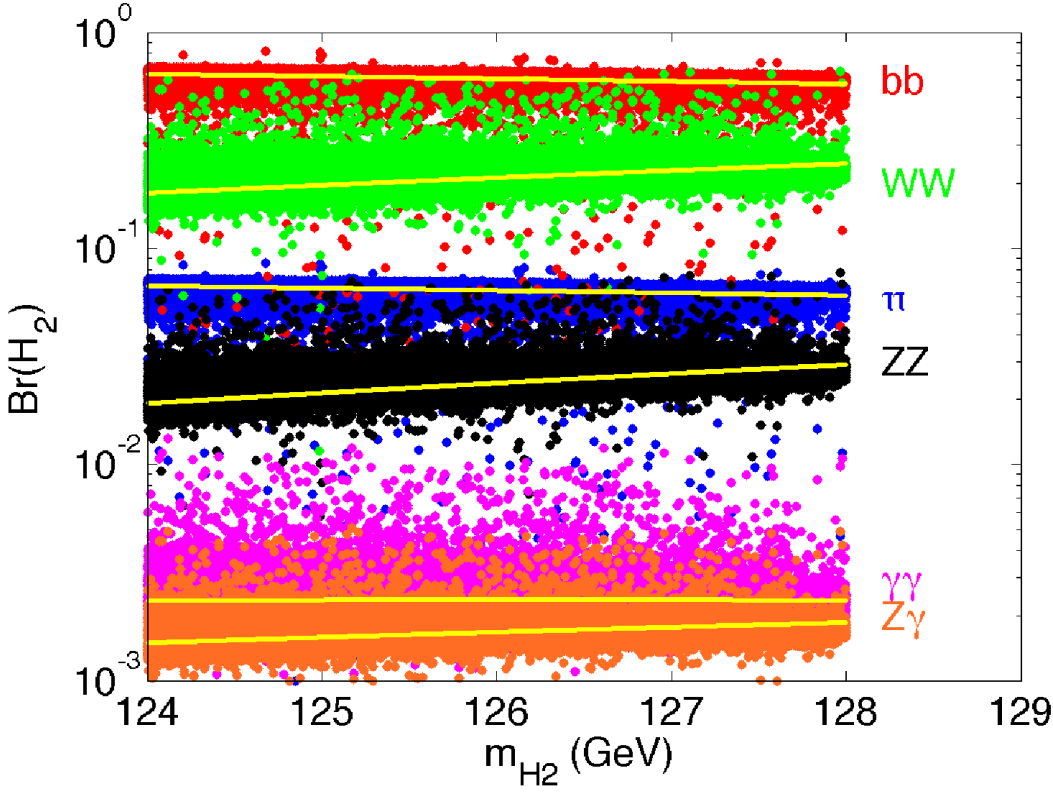
Yellow Lines are reference lines for SM Higgs
From now on,
Left- H1-126 Case
Right- H2-126 Case

VBF < SM
ggH could be greater than SM due to quark, squark loop

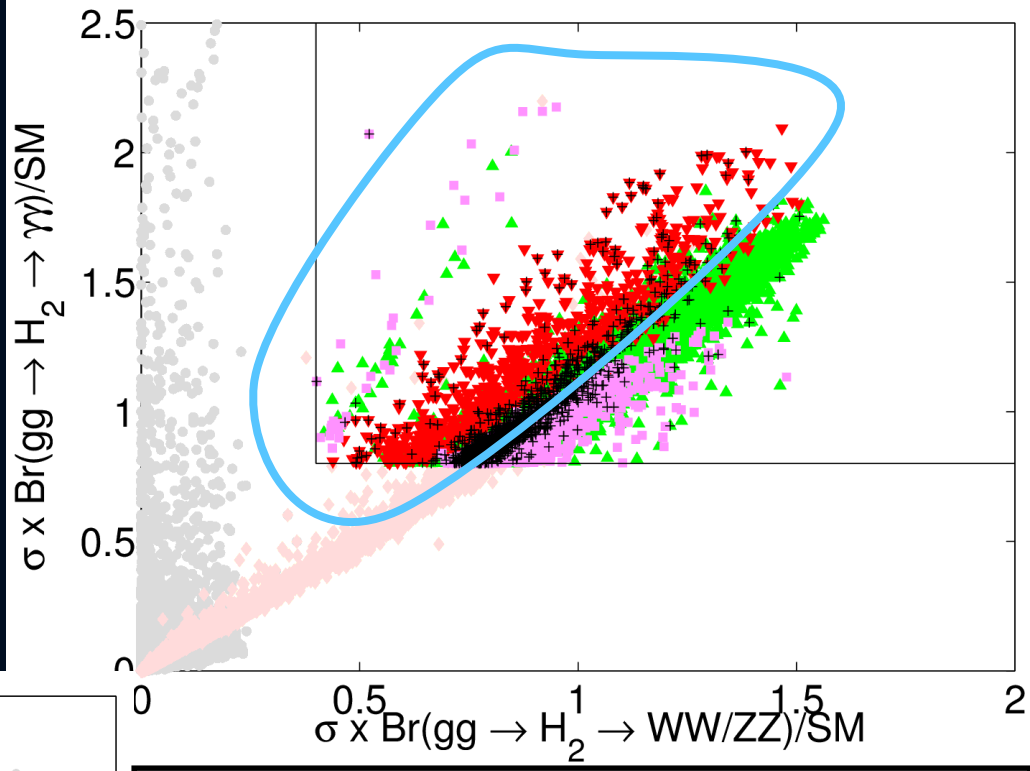


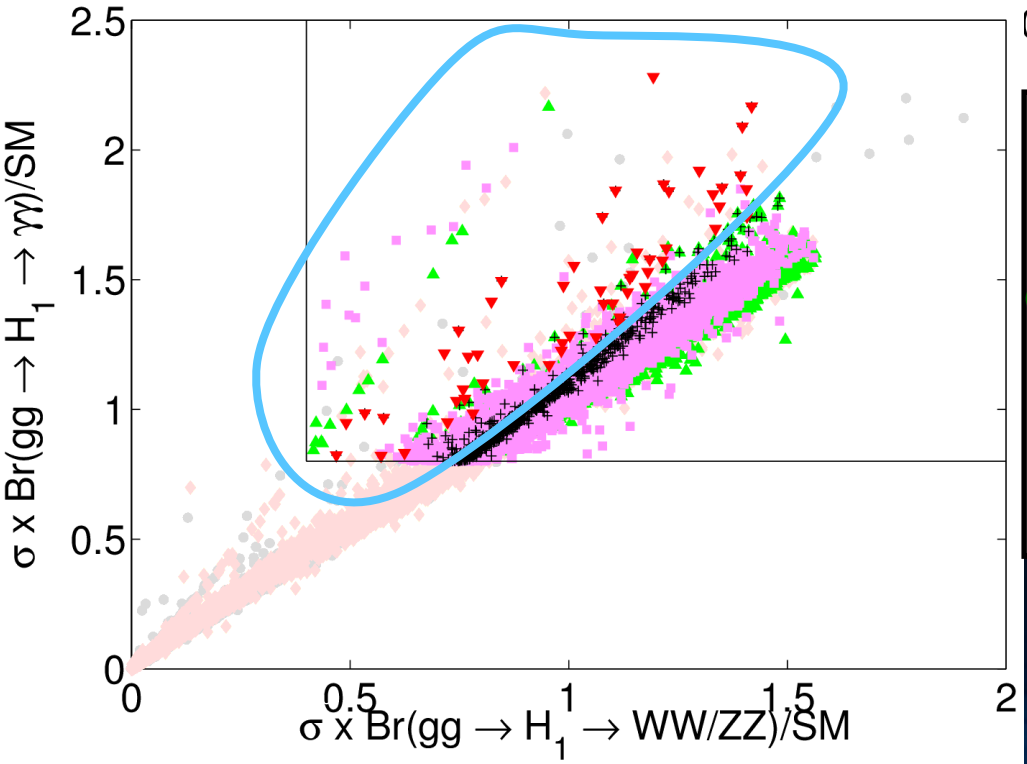
SM-Like Higgs: Decays I





SM-Like Higgs: Signal strength of γγ/ZZ

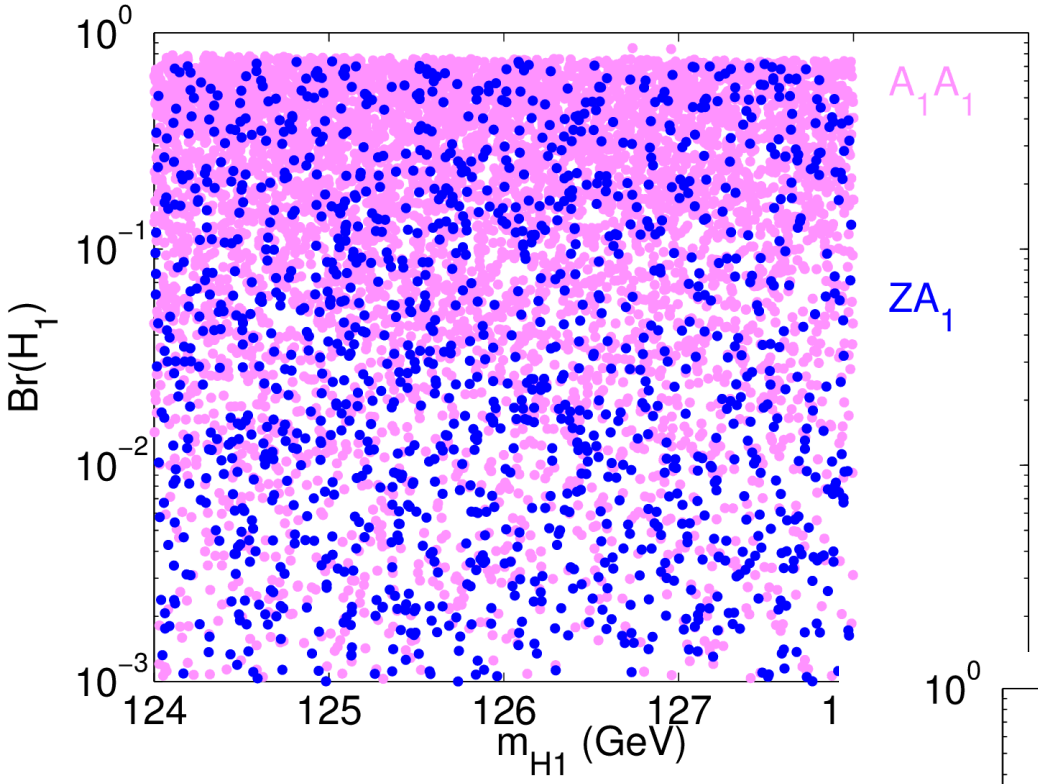




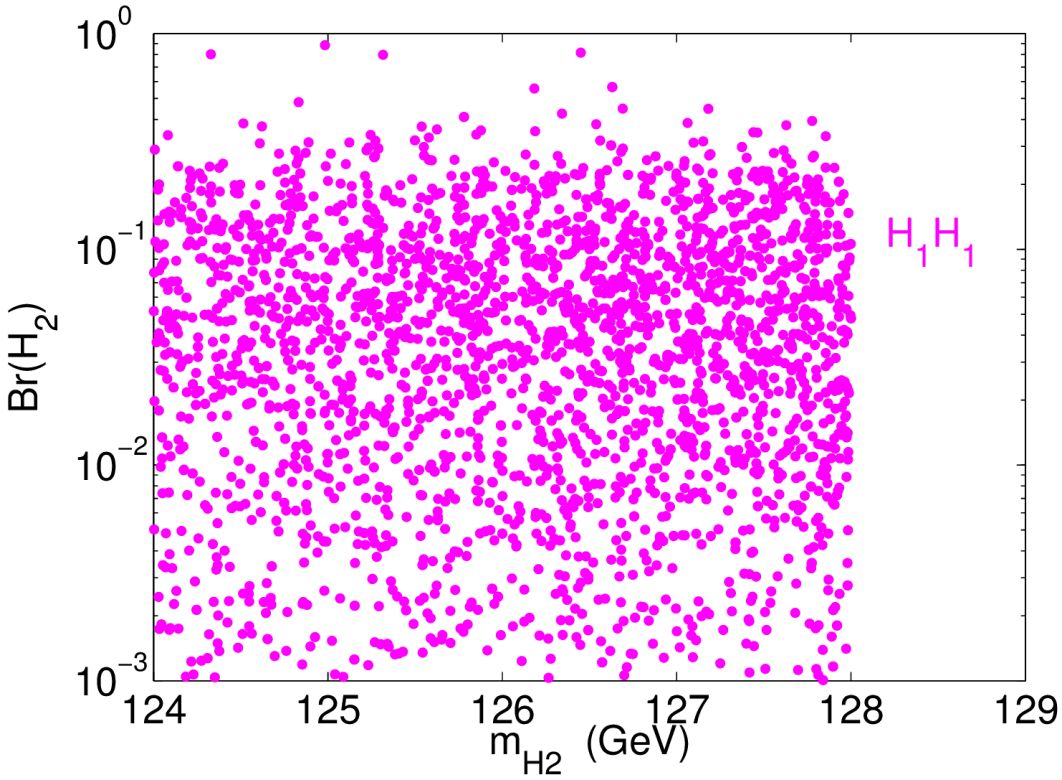
- grey: pass exp
- pink: $124 < m_{H1} < 128$ GeV
- green, red, purple, black: satisfy σXBr(γγ, WW)
  - H_1 region IA, $m_{A1} > m_{H1}/2$, $|\xi_{H1}^{hv}|^2 > 0.7$
  - H_1 region IB, $m_{A1} > m_{H1}/2$, $|\xi_{H1}^{hv}|^2 < 0.7$
  - H_1 region II, $m_{A1} < m_{H1}/2$, $H_1 \rightarrow A_1 A_1$
- black: perturbativity till m_{GUT}

Modified due to stop loop with large L-R mixing

SM-Like Higgs: Decays II

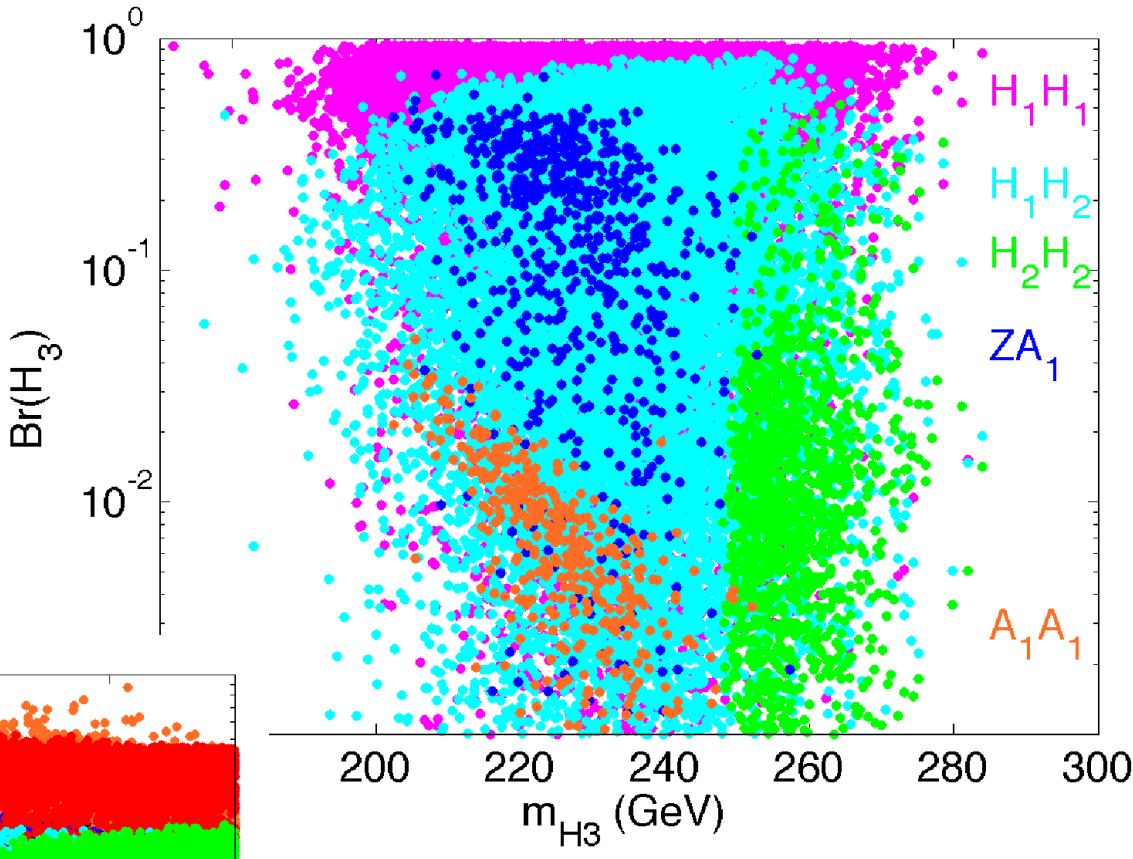


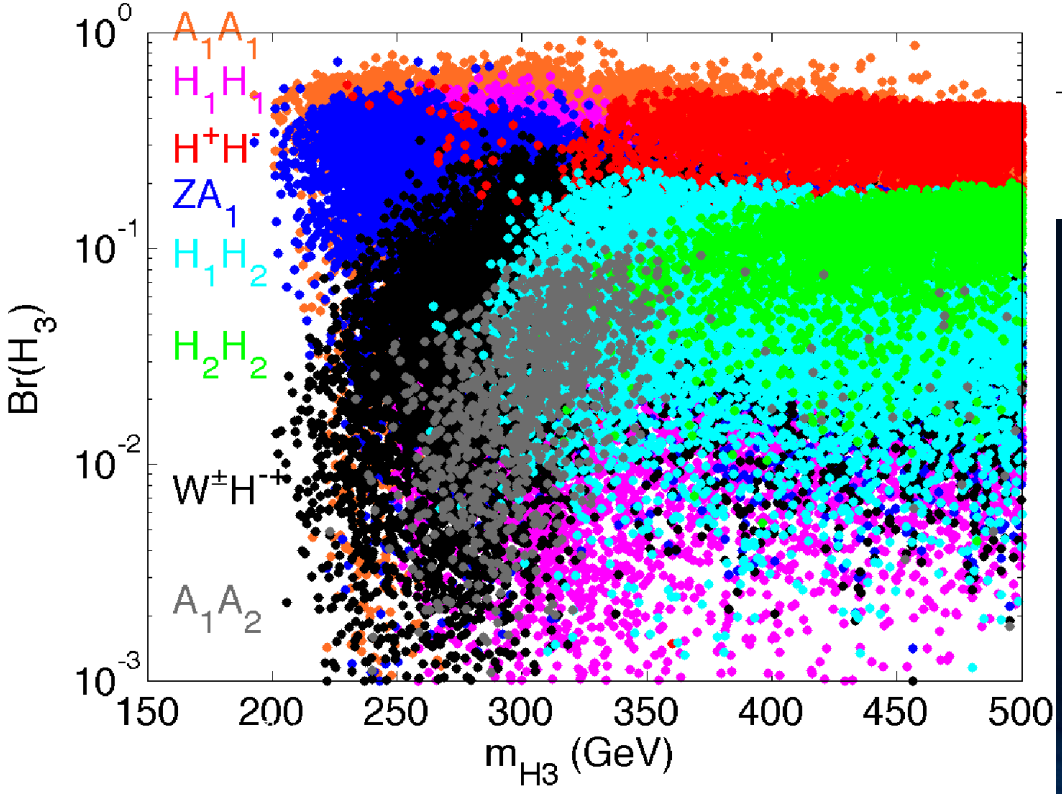
SM-like Higgs could have large branching fractions to other Higgs bosons



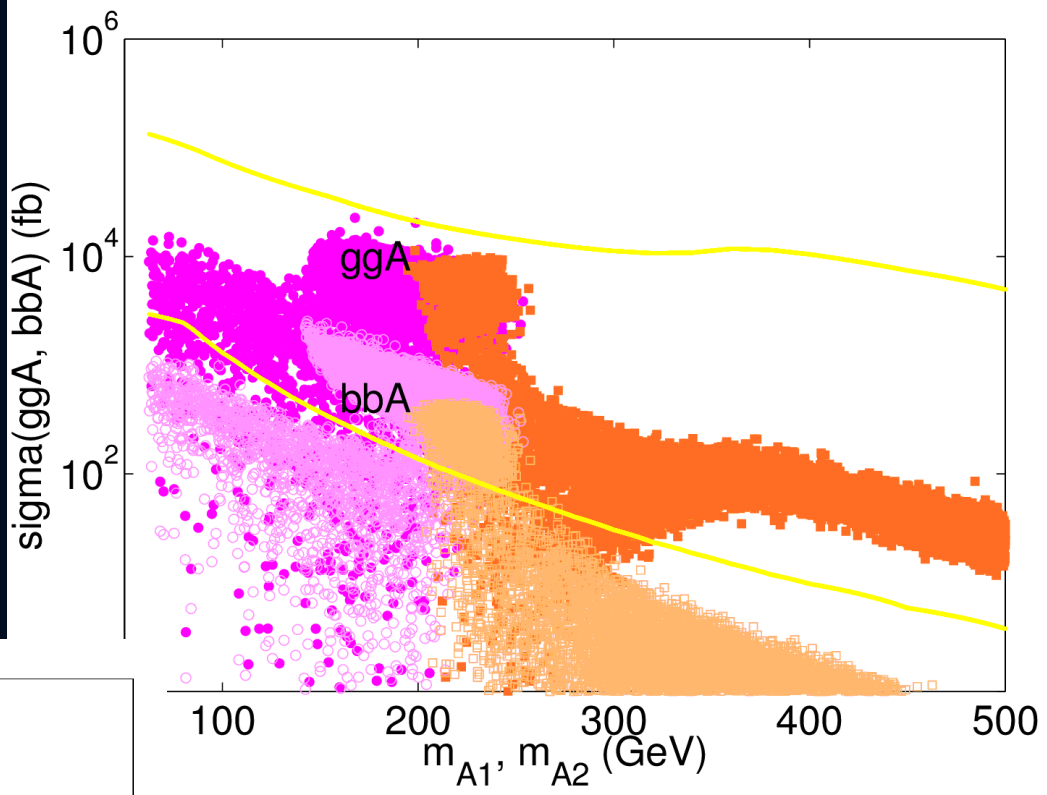
Examples: H_3 Decay

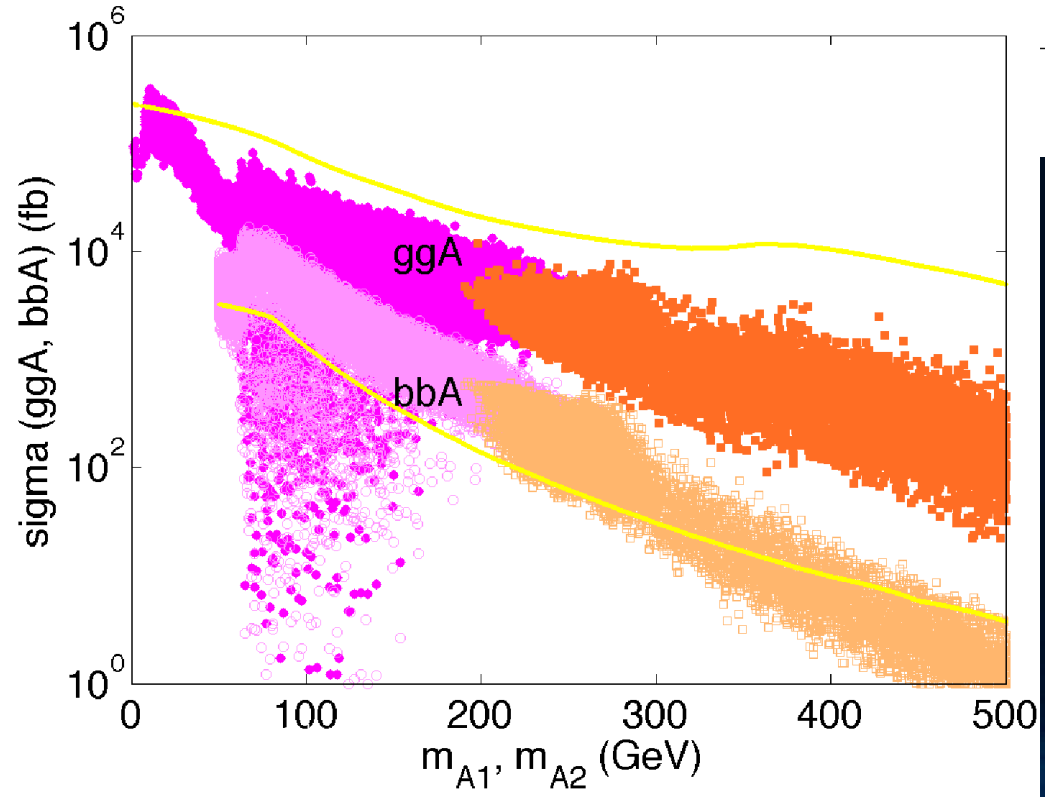
Due to time limits, only present a few Higgs bosons properties. More in our paper, 1303.2113



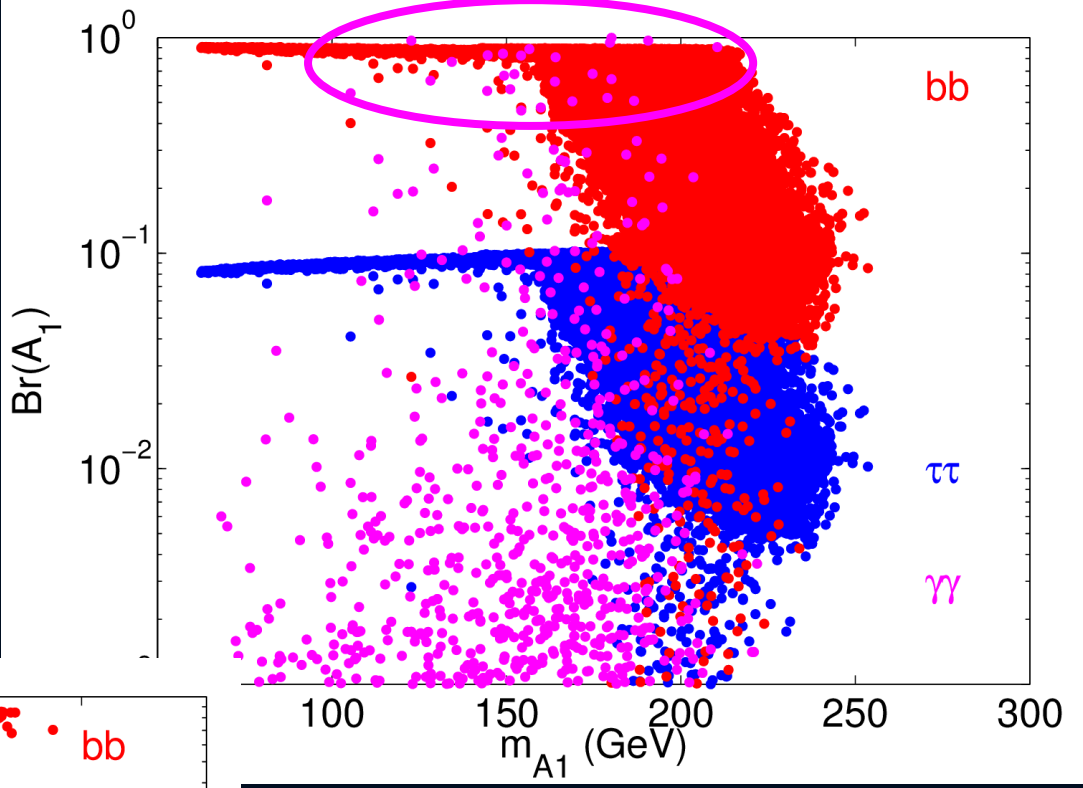


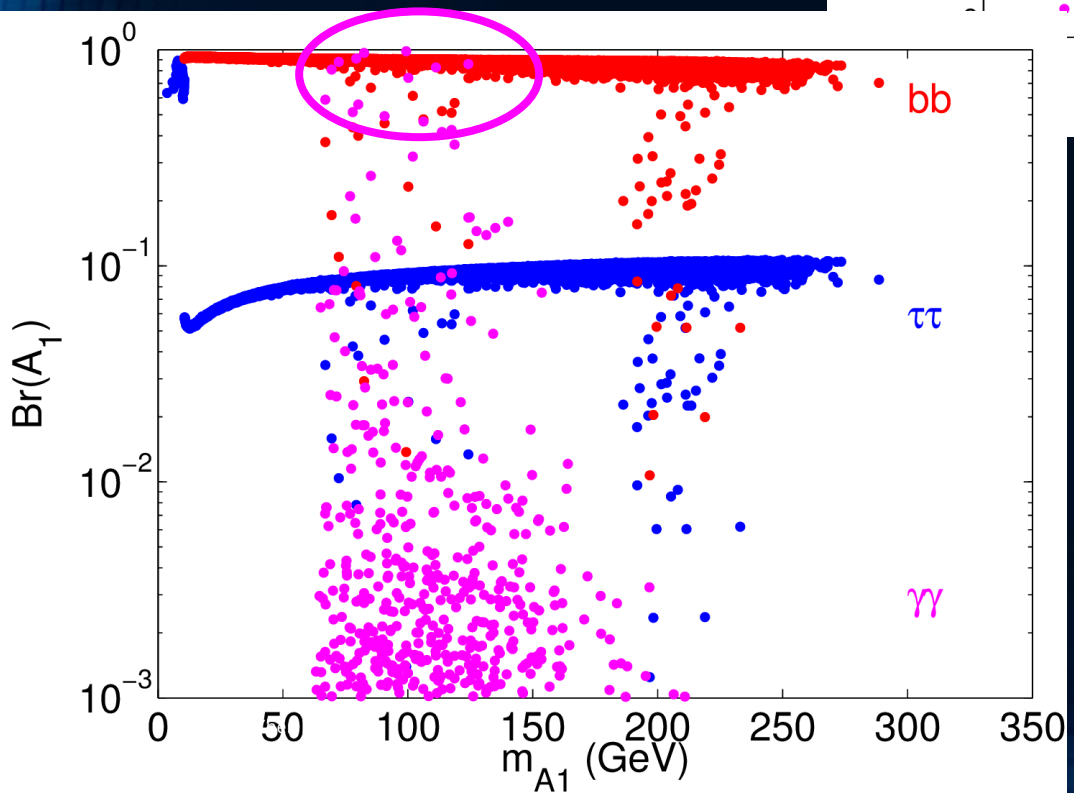
Examples: A1, A2 productions





Examples: A1 Decay





Diphoton dominant: Almost pure singlet, With chargino loop induced diphoton couplings

Summary on Non-Standard Decays

- **H_1-126, decay to Higgs boson**

$$H_1 \to A_1A_1,\ ZA_1,$$
$$H_2 \to A_1A_1,\ ZA_1,\ H_1H_1,$$
$$H_3 \to A_1A_1,\ H_1H_1,\ ZA_1,\ W^\pm H^\mp,\ A_1A_2,\ H_1H_2,\ H_2H_2,\ H^+H^-,$$
$$H^\pm \to W^\pm A_1,\ W^\pm H_2,\ W^\pm H_1,$$
$$A_1 \to ZH_1,$$
$$A_2 \to A_1H_1,\ A_1H_2,\ W^\pm H^\mp,\ ZH_1,\ ZH_2,\ ZH_3,\ A_1H_3,$$

Channels allowed in MSSM (decoupling solution).*However, H, A, H^+ in MSSM are usually too heavy for LHC/ILC reach. (more from Carlos Wagner's talk)

- **H_2-126, decay to Higgs bosons**

$$H_2 \to H_1H_1,$$
$$H_3 \to H_1H_1,\ H_1H_2,\ ZA_1,\ A_1A_1,\ H_2H_2,$$
$$H^\pm \to W^\pm H_1,\ W^\pm A_1,\ W^\pm H_2,$$
$$A_1 \to ZH_1,\ ZH_2,$$
$$A_2 \to ZH_1,\ A_1H_1,\ A_1H_2,\ ZH_2,\ W^\pm H^\mp,\ ZH_3,\ A_1H_3,$$

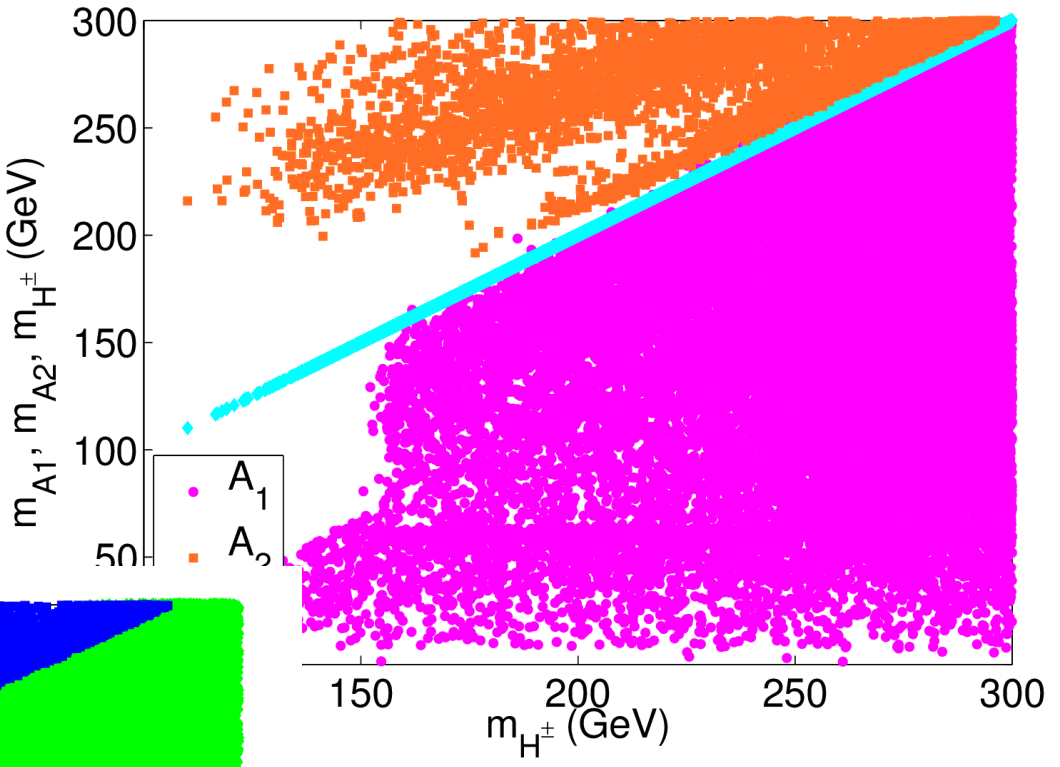
Summary

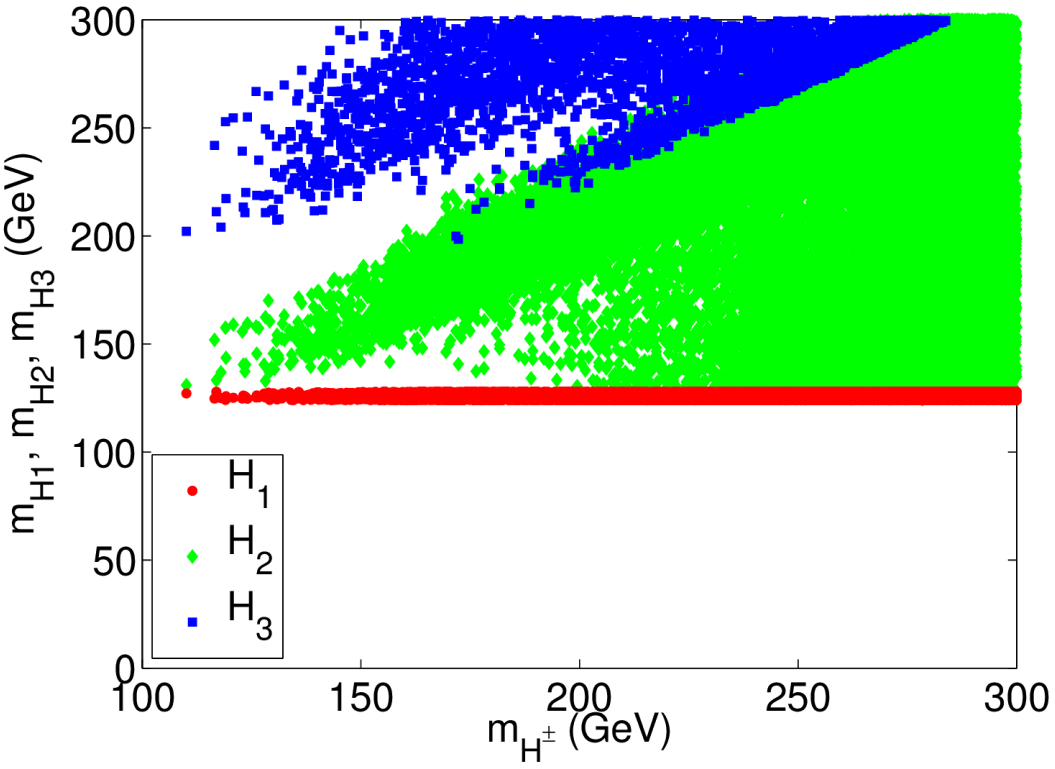
Thank you!

- SM-like Higgs may not be so SM-like. **Continue SM Higgs precision measurements.**
- Plenty of room for low-lying Higgs Bosons. **Continue Standard Higgs searches on SM modes (decays to qq, VV, ll).**
- Many new discovery channels should be considered. **Don't limit ourselves! (see more from Rouven Essig's talk.)**

Model independent searches very important, like total width--necessary for couplings strength, invisible modes, exotic modes. See ILC talks, MuC talks.

BACKUP SLIDES


300
250
200
150
100
50
m_{A1}, m_{A2}, $m_{H^\pm}$ (GeV)
A_1
A_2
150
200
250
300
$m_{H^\pm}$ (GeV)


300
250
200
150
100
50
0
m_{H1}, m_{H2}, m_{H3} (GeV)
H_1
H_2
H_3
100
150
200
250
300
$m_{H^\pm}$ (GeV)

$1 < \tan\beta < 10$

$0\ \text{GeV} < m_A < 200\ \text{GeV}$

$100\ \text{GeV} < \mu < 1000\ \text{GeV}$

$0.01 < \lambda < 1$

$0.01 < \kappa < 1$

$-1200\ \text{GeV} < A_\kappa < 200\ \text{GeV}$

$100\ \text{GeV} < M_{3SU}, M_{3SQ} < 3000\ \text{GeV}$

$-4000\ \text{GeV} < A_t < 4000\ \text{GeV}$

decoupling other parameters (3 TeV)

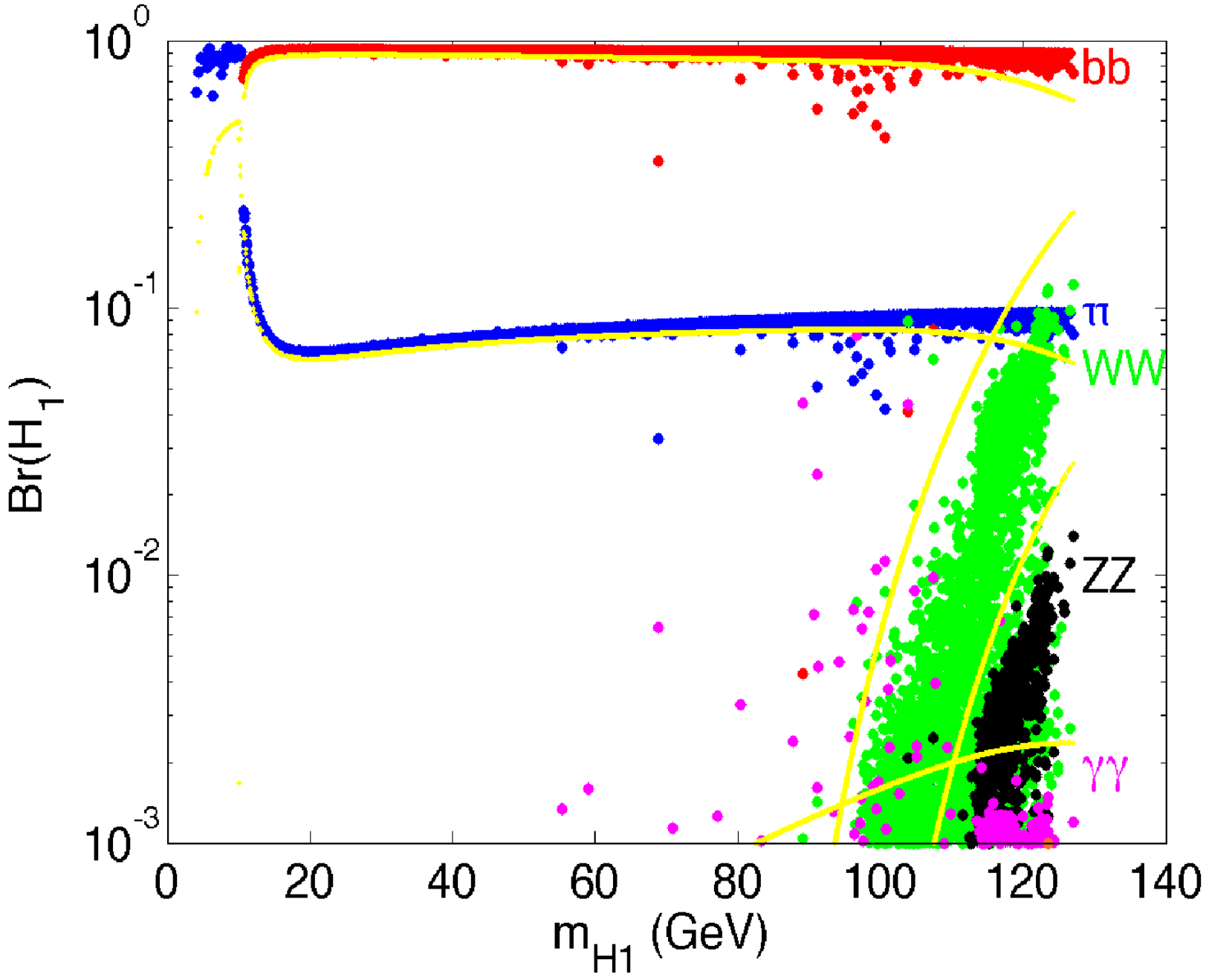
NMSSMTools

Parameter regions

	H_1 126	perturbativity	$m_{A1}<m_{H1}/2$
tanβ	1 to 3.5	1.5 to 2.5	1 to 3.5
m_A	0 to 200 GeV	150 to 200 GeV	100 to 200 GeV
μ	μ ≤ 500 GeV	100 to 150 GeV	100 to 200 GeV
λ	≥ 0.55	0.55 to 0.6.5	≥ 0.55
κ	≥ 0.3	0.3 to 0.5	≥ 0.5
A_κ	-1200 to 200 GeV	-150 to 100 GeV	-50 to 30 GeV
A_λ	-650 to 300 GeV	-30 to 230 GeV	-150 to 150 GeV
$\|A_t\|$		≥ 1200 GeV	

Parameter regions

	m_{H2} ~ 126	H_2 126	perturbativity	$m_{H1}<m_{H2}/2$
tanβ	>1	1 to 3.25	1.5 to 2.5	1.25 to 2.5
m_A	0 to 200	100 to 200 GeV	170 to 200 GeV	125 to 200 GeV
μ	100 to 300	100 to 200 GeV	100 to 130 GeV	100 to 150 GeV
λ	0 to 0.75	0.4 to 0.75	0.5 to 0.7	0.5 to 0.75
κ	0 to 1	≥ 0.05	0.05 to 0.6	≥ 0.3
A_κ	-1200 to 50	-1200 to 50 GeV	-300 to 50 GeV	-500 to -250 GeV
A_λ	-600 to 300	-300 to 300 GeV	0 to 300 GeV	0 to 200 GeV


10^0
10^{-1}
10^{-2}
10^{-3}
$Br(H_1)$
bb
ττ
WW
ZZ
γγ
0
20
40
60
80
100
120
140
m_{H1} (GeV)